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Abstract: OBJECTIVES Narrowed radicular pulp spaces are frequently observed in teeth wearing extended restorations. The present study investigates whether the narrowing of particularly the radicular pulp space can be attributed to coronal restorations. MATERIALS AND METHODS The study is based on an anonymized copy of the cone-beam computed tomography (CBCT) database from the Center of Dental Medicine of the University of Zurich. One hundred CBCT scans were selected out of 7317 data sets to match either a crowned (group A; n = 50) or a filled tooth (group B; n = 50) with a contralateral healthy, unrestored, and caries-free control tooth at the same position, respectively. Cross-sectional images were adjusted in the coronal, middle, and apical root third of each subjected tooth. Screenshots were taken in that position and analyzed. The area occupied by the pulp space was determined as percentage area of the whole root diameter on each cross section. The resulting values were compared between restored and control teeth. RESULTS In both groups (crowned and filled teeth) and in all the three root thirds, the radicular pulp space was significantly narrower in the restored teeth compared to the control teeth. The strongest narrowing effect was observed in the coronal root third and it decreased towards the apical root third (both groups). CONCLUSIONS Teeth with coronal restorations show within the limitations of the present study a significant narrowing of their radicular pulp space. CLINICAL RELEVANCE The asserted narrowing could have a complicating effect if root canal treatment becomes necessary in those teeth.

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Narrowing of the Radicular Pulp Space in Coronally Restored Teeth

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Abstract:

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Materials and Methods: The study is based on an anonymized copy of the cone-beam computed tomography (CBCT) database from the center of dental medicine of the university of zurich. One hundred CBCT scans were selected out of 7317 data sets to match either a crowned (group A; n=50) or a filled tooth (group B; n=50) with a contralateral healthy, unrestored, and caries-free control tooth at the same position, respectively. Cross-sectional images were adjusted in the coronal, middle and apical root third of each subjected tooth. Screenshots were taken in that position and analyzed. The area occupied by the pulp space was determined as percentage area of the whole root diameter on each cross-section. The resulting values were compared between restored and control teeth.

Results: In both groups (crowned and filled teeth) and in all three root-thirds, the radicular pulp space was significantly narrower in the restored teeth compared to control teeth. The strongest narrowing effect was observed in the coronal root third and it decreased towards the apical root third (both groups).

Conclusions: Teeth with coronal restorations show within the limitations of the present study a significant narrowing of their radicular pulp space.

Clinical Relevance: The asserted narrowing could have a complicating effect if root canal treatment becomes necessary in those teeth.

Key words: Dental pulp calcification, pulp canal, pulp stone, pulpal obliteration, root canal, secondary dentine

1. Introduction

An advanced calcification of the dental pulp space is a common clinical finding. It is found in decayed or even in clinically healthy mature teeth, in the latter case mostly in those of older individuals [1-3].

This narrowing or even complete obliteration process can lead to a significant clinical task if root canal treatment (RCT) becomes necessary [4-6]. Presumably, in a significant number of cases it also results in failure of RCT by possible miss of the root canal, by perforation, or even instrument separation, whereas reliable epidemiological data on this presumption are not available [7]. A supposable reason for the lack of this knowledge is, that most studies investigating failures of RCT or reasons for tooth extraction do not look at this eventually impairing parameter [8-11].

Authors mostly differentiate in their manuscripts between narrowing or calcification processes in the pulp chamber on one side and in the radicular pulp space on the other side. While both may affect the technical feasibility of RCT, the former impedes more the preparation of an access cavity and the locating of the root canals, while the latter rather complicates root canal preparation.

Different types of hard tissue can be formed in coronal and radicular aspects of the pulp space. A first type comprises regular or irregular forms of secondary or tertiary dentin. They are deposited

at the coronal or radicular pulpo-dentinal walls [12-19]. The second type forms primarily in the pulpal interstitium and comprises true or false denticles and according subtypes. These denticles can spread and with advanced growing also lead to complete obstruction of the pulpal lumen. They can become attached or embedded into the progressing pulp space walls [20-22].

Conditions for hard tissue-forming processes may be physiological or pathological. For instance the height and the width of the pulp chamber decreases physiologically with age [17, 18, 23]. Regular and irregular forms of secondary dentin are formed and lead to smaller diameter of coronal and radicular pulp spaces. Also false denticles increase in older individuals physiologically. But on the other hand, cavity preparation, carious decay and the presence of coronal restorations increase the number of interstitial calcifications in the coronal pulp chamber and especially lead to tertiary dentin formation [20, 24-28].

A gap in today´s knowledge about calcifying processes can be observed in a certain clinical picture that is found in everyday endodontic practice. Frequently, when RCT becomes necessary, a severely obliterated radicular pulp space can be observed on the diagnostic radiograph from a tooth wearing an extended restoration (Fig. 1). At the same time, pulp spaces of healthy neighboring teeth may commonly appear normal. The narrowing of the radicular aspect of the pulp space cannot be explained with the presently accepted concepts of tertiary dentin formation as a consequence of the restoration, because by definition, the deposition of tertiary dentin takes place strictly underneath the affected dentinal tubules at the site of impact [19]. Frequently however, such obliterations are observed in roots of just coronally restored teeth. While also other calcification processes cannot independently explain this clinical picture, the effective narrowing of the radicular pulp space has not yet been directly related to coronal restorative procedures. Anyhow, this seems necessary, because even idiopathic obliterations may be observed in unrestored and non-traumatized teeth [29, 30].

Therefore, the aim of the present study was to investigate whether coronally restored teeth show a narrowed radicular pulp space compared to healthy, unrestored, and caries-free control teeth. The null hypothesis was, that there is no difference between these two groups of teeth.

2. Materials and Methods

The study is based on the cone-beam computed tomography (CBCT) database of the Center of Dental Medicine of the University of Zurich, containing all CBCT scans taken between 1st June 2008 and the 1st Dec 2013. All scans were recorded with the same calibrated CBCT device (KaVo 3D eXam, KaVo Dental GmbH, Biberach an der Riß, Germany). The database was anonymized with customized software and stored on a separate portable hard disk (Toshiba DT 01 ACA 200, 2TB, Toshiba Corporation, Minato, Japan) for further scientific processing. A total of 7317 CBCT scans were available. During and after the anonymization process, no personal information of any patient was retraceable for the investigators. Ethical approval was requested and given for the processing of the anonymized data by the local ethical committee (Kantonale Ethikkommission Zürich, submission No. KEK-ZH-Nr. 2014-0099).

Osirix (v5.8.1, 64-bit, Pixmeo, Bernex, Switzerland) was used as DICOM-viewing software in combination with a desktop computer (Mac mini, Intel core 2 duo, Apple Inc., Cupertino CA, USA) and a standard display screen (Asus MW 201, ASUSTeK Computer Inc., Taipeh, Taiwan). The CBCT scans were searched for 50 cases per group, in which mature teeth wearing a full crown (group A, n=50) or a conventional filling (group B, n=50) could be matched with contralateral control teeth that were free of caries, restorations or any defects. The control teeth had to be located contralaterally in the same jaw at the same position (Fig. 2).

Exclusion criteria were deciduous teeth, mature teeth with incomplete root development, radiographical signs for marginal or apical periodontitis, cysts, present root fillings or pulp cappings, developmental disorders, present fixed orthodontic devices, incisor teeth, cases with an obvious history of a traumatic dental injury (e.g. by presence of osteosynthesis material), and uncertainty about the tooth´s natural position or number (e.g. whether a tooth was a first or a second premolar / molar).

The matched teeth were adjusted with the viewing software in a plane tangential to their position in the dental arch (as in 2-dimensional paralleling-technique x-ray projections). The length of the root was then measured from the cemento-enamel junction to the root tip. The root was divided into coronal, middle, and apical third and cross-sections through the center of each root third were selected in the viewing software (Fig. 3 a). A screenshot was taken from each cross-section and saved as a JPEG-file. Hence, six images resulted for each case (three from test and three from control tooth, respectively). The overall 600 images were then completely blinded and randomized, so that no information about the pertaining group or the localization of the cross section was visible. A blinded investigator then completed the definite measurements.

The image-files were transferred to a universal analyzing-software (ImageJ, V1.48d, Wayne Rasband, National Institutes of Health, Bethesda, Maryland, USA). Outer root margins and the circumference of the radicular pulp space were traced using the polygon selection tool (Fig 3 b-e). This allowed the measurement of the corresponding area occupied by the whole root and by the pulp space for each cross-section. The measurements were done from one blinded investigator in a darkened room using a laptop computer (Acer Aspire, S3-951, Intel Core i5-2467M, Intel HD 3000, 13.3) with a screen resolution of 1366x768 pixels.

After accomplishment of the measurements, the resulting data were decoded and allocated to the pertaining group, tooth and root-third. Subsequently, the percentage portion of the area occupied

by the root space within the whole root diameter was calculated for each cross-section. In multi-rooted teeth or teeth with more than one root canal in a single root, this was done by dividing the sum areas demarked by the outer radicular circumferences by the sum of the areas occupied by the root spaces. The resulting percentage value of the restored tooth was subtracted from the value of the control tooth in each case and both groups. The obtained result indicated by its algebraic sign, whether the pulp space of the restored tooth occupied a greater or smaller percentage area of the outer root circumference, compared to the control tooth.

For statistical analysis the software SPSS Statistics (Version 20, IBM, Armonk NY, USA) was used. After an explorative data analysis, a one- sample t-test was calculated within each group for each root third in order to estimate, whether restored teeth show a narrowed radicular pulp-space diameter and in which root third it can be expected. To get information about a possible effect over the whole root length, data of the three root thirds were summarized for each tooth. The one-sample t-test was then repeated between test- and control teeth. The significance level was set at 5% (p=0.05).

Subsequently, a repeated measures analysis of variance (ANOVA) was calculated within the two groups to estimate, whether the location within the root has a significant influence on the possible narrowing of the root space diameter. Therefore, Mauchly´s test of sphericity followed by Greenhouse-Geisser and Hunyh-Feldt correction was calculated. In a next step, each possible pair of root thirds was compared within the two groups and tested for statistical difference.

To allow comparisons between group A and B, the distribution of included teeth to their pertaining position in the upper or lower jaw was analyzed separately for group A and B. For this purpose, a Kolmogorov-Smirnov test and Chi-Square test was performed in each jaw and each group. Subsequently, the number of each tooth´s position was summarized from upper and lower jaw and the analysis was repeated without differing between the jaw, just between the tooth´s

position and the pertaining group (A or B). Significance level was kept at 5% (p=0.05).

For observer reliability testing, ten percent of the blinded and randomized screenshots were re-measured twenty months after and under the same conditions as described above. Intra-class-correlation coefficient was calculated with a two-way mixed model over all measured areas (up to seven areas for one screenshot) at the two time points. Observer reliability was expected when a value between 0.8 and 1.0 would be achieved.

3. Results:

More than four thousand CBCT-scans had to be searched to achieve 50 cases as requested in group A, where a tooth restored with an artificial crown could be matched with a contralateral healthy, unrestored, and caries-free control tooth. Intra-class-correlation coefficient was calculated to be 0.99 (95%CI: 0.99 – 1.00; $p<0.001$), therefore observer reliability was accepted and considered as excellent. A boxplot depicting the percentage differences of root space diameter between restored and control teeth is shown in Fig. 4. In the coronal root third of the crowned teeth (group A), the mean narrowing of the root space diameter was 4.3% (95% CI: 2.8 to 5.8%), in the middle root third it was 4.0% (95% CI: 3.1 to 4.9%), and in the apical root third it was 1.5% (95% CI: 0.9 to 2.0%). In the filled teeth (group B), the mean narrowing of the root space diameter was 7.4% (95% CI: 6.0 to 8.8%) in the coronal root third, 2.4% (95% CI: 1.6 to 3.2%) in the middle root third, and 1.4% (95% CI: 0.6 to 2.3%) in the apical root third. In all these root thirds of both groups, the measured percentage narrowing was significantly different from zero, even at a 1% significance level ($p<0.01$).

Within the two groups, the level of the root had a significant influence on the degree of narrowing of the root space diameter, shown by significant positive results of the Mauchly-test, the Greenhouse-Geisser and Huynh-Feldt corrections (again at 5% and even at the 1%

significance level).

The testing between the root-thirds revealed a significant difference in narrowing of the root space between the coronal and the apical, and also between the middle and the apical root third within group A. But there was no significant difference between the coronal and the middle root third in this group. Within group B, significant differences were found between the coronal and the middle, and between the coronal and the apical root third. Here, no significant difference could be found between the middle and the apical root third (compare Fig. 4).

After summarizing data from the three root thirds in order to test for an effect over the whole root length, 3.24% (95% CI: 2.54 to 3.94) of mean narrowing could be measured in group A and 3.75% (95% CI: 3.04 to 4.45) in group B. The narrowing effect was statistically significant within both groups ($p<0.01$ in group A; $p<0.01$ in group B). However, comparing the effect of the two groups directly with each other, no statistical significance could be detected ($p=0.74$).

Teeth were equally distributed within group A and B over their pertaining position when differentiating between and when summarizing teeth from upper and lower jaw. Both statistical tests came to the same results in all tested subgroups. Nevertheless, within group A, more canines, first and second premolars were included compared to group B, where in sum more first and second molars were included. No third molars were included in neither group.

4. Discussion:

The present study is a split-mouth intra-individual case-control analysis of fully anonymized CBCT-scans retrieved from the database of the center of dental medicine of the university of Zurich. The core question was, if coronally restored teeth show a narrowed radicular pulp space compared to healthy, unrestored, and caries-free control teeth.

In both groups and each root third of the present analysis, the radicular root space is narrowed in

the teeth wearing coronal restorations compared with those of unrestored and caries-free control teeth. Subsequently, the null hypothesis has to be rejected. The effect seems to decrease from the coronal towards the apical root third. It was significantly stronger in the coronal root third, when directly compared with the apical root third (in group A and B).

Regarding the results, the mean narrowing of the coronal root third seemed to be even stronger in "just filled" teeth compared with those restored with a full crown. This appears surprising, because the preparation of a full crown is assumed to lead to a stronger pulpal irritation than the insertion of a dental filling. But these results are relativized when comparing the percent values of the middle root third. Here, crowned teeth showed a stronger mean narrowing compared with filled teeth. In the apical root third, both groups had nearly the same percent effect. Due to failing information about the history of the restoration placement, the absolute percent values of the results should be considered with carefulness. General effects may be read off the present data, but a clinical significance cannot yet be formulated.

An interesting trend, however, is the aforementioned difference of the narrowing effect from coronally towards apically. This finding corresponds precisely to a clinical experience endodontists utilize every day. In teeth showing an advanced obliteration of their pulp space, location of the root canal with the help of an operation microscope frequently becomes necessary. The search commonly has to be pursued into the coronal and sometimes into the middle or even apical root third. But when once a residual root canal lumen is found and opened, it mostly is negotiable until the apical foramen. The cause is a directed and obviously concentric pulp space narrowing (and finally obliteration) from the coronal towards the apical portion of the root.

The questioning of the present study has, to the best of the author's knowledge, not been attended to in detail in a systematic setup before. Even though it is an every day clinical finding. A possible reason may be, that in the era before the CBCT technic was available, the question could

not be answered without extracting the investigated teeth. At that time, no method with a comparatively low radiation exposure existed to measure the radicular pulp space diameter of a tooth in situ.

With the design used in the present study, no information is available about the period of time regarding how long a particular restoration already has been in situ. The anonymization process of the existing CBCT data, which was mandatory for legal and ethical reasons, made a subsequent acquisition of those data after case selection impossible. This means that possibly cases are included, in which the restoration may have been placed just recently before the CBCT scan was recorded. In such possible cases, the used method would underestimate the effect of the restoration on the narrowing of the radicular pulp space, because the time needed for this hard tissue forming process may have been to short. Additionally, no information is available about how long generally this obvious narrowing process after restorative procedures lasts in the root. On the other hand, it might be assumed; that teeth with crowns and extended fillings may have had a history of severe carious decay before placement of a crown. This presumable carious history may have affected the pulp before. These issues would be valuable information for a prospective clinical study set up. But here, further investigations are needed.

In this context, it is worth mentioning that in group A teeth were included equally if they showed a single crown or if they were part of a bridge construction. They were included, because all those teeth had undergone a certain preparation trauma with a possible effect on narrowing processes of the root space. But between these two restoration types, different occlusal loading patterns can be expected which might have a concomitant effect on the narrowing, but which could not be detected with the present method. To answer this question, also further investigations would be needed.

Also no information is available about the reason due to which the restoration has been placed.

Whether there was caries, a fractured cusp or another hard tissue defect prior to the dental restorative intervention. No information is available about age, gender, or general health status of the patients. Since other studies have revealed that these factors may have an influence on different other hard tissue forming processes in the pulp space [1-3, 17, 18, 20, 23-25], it cannot be excluded that they may also have an influence on the narrowing of the pulp space analyzed in the present study. The most common reason for radicular pulp canal obliteration, which is a traumatic dental injury, was attempted to exclude in the present study by non-inclusion of incisor teeth, which are the most frequently affected teeth in dental traumata [4, 6, 31, 32].

Data acquisition of the extend or diameter of the radicular pulp spaces is done in the present study by analyzing one 2-dimensional cross section for the three different root parts, respectively. This means 2-dimensional areas are used as surrogate outcome measurements for 3-dimensional target volumes. This method comprises some impreciseness, but due to randomization and blinding of the data before taking the measurements, a human bias was definitely excluded. The correlation of the determined statistically significant results with clinical findings, however, can be interpreted as an indication of the validity of the data.

First selection of the cases out of the 7317 data sets was done on the basis of the othopanthomogram-viewing the DICOM-viewing software offered. This orthopantomogram-viewing gives a good overview of all teeth, but has a minor quality regarding detail resolution. In a number of cases, this viewing showed artefacts around the metal-dentine interface that can e.g. be observed in Fig. 2 a) as marginal radiolucencies of crowned teeth (compare tooth #44). During the analysis, reliable measurements could be performed in the selected cases without occurrence of such an artefact in the cross-sectional viewing of the target region of the coronal root third. A possible reason next to the better quality and resolution of the cross-sectional viewings is, that that there was always a distance from such an artefact, because axial cross-sections of the tooth

were taken in the middle of each root third. Therefore, a distance of some millimeters from the margins of a crown was guaranteed.

Nonetheless, the used method comprises a slight inaccuracy and as already mentioned, the absolute values of the resulting data should therefore be considered with carefulness.

On the other hand, by the use of the split-mouth design, other patient immanent confounding effects like e.g. age, gender, and general health could be excluded. If a narrowing effect was measured, it may not have occurred alone due to age, gender, or general health status of the patient. The impact of the restorative procedure can thus be considered as most likely. The high significance of the results in the background of the aforementioned might be interpreted as more indicative for the assumed narrowing effect in the radicular pulp space of restorative interventions.

5. Conclusions:

In summary, the results of the present study indicate that the radicular pulp space is narrowed in coronally restored teeth (crown or filling), compared to unrestored and caries-free control teeth. The narrowing was present in all three root thirds, while it was strongest in the coronal and least in the apical root third.

Figures:

Fig. 1 Radiograph showing lower right second premolar, first, and second molar of a 57-year-old female patient. All three teeth wear extended restorations and the molars show signs of calcification and narrowing processes of their pulp spaces, especially in their mesial roots. The first molar reveals an apical radiolucency at its mesial root. Root canal treatment was indicated

on this tooth

Fig. 2 a) Matching of a crowned tooth #44 with a contralateral control tooth at the same position #34 (group A) and **b)** a filled tooth #46 with a contralateral control tooth #36 (group B)

Fig. 3 a) Measurement schematic; total root length measured from cemento-enamel junction (CEJ) to apex and divided into coronal (CRT), middle (MRT) and apical root third (ART). The screenshots of cross sections were taken at 1/6, 1/2, and 5/6 root length respectively (dashed lines)

b-e) Cross sectional screenshot of coronal root third of a molar. Yellow lines indicate four measurements in the same screen shot of areas occupied by the outer root margin (b) and by the radicular pulp space (c-e) in a multi-rooted molar

Fig. 4 Boxplots showing the results within group A and B (crowned and filled teeth, respectively). Each box indicates the percentage difference (y-axis) between the root space diameter of test and control teeth within one root third (x-axis; W1 = coronal root third, W2 = middle root third, W3 = apical root third). Positive values indicate a narrowed pulp space within restored teeth compared to their pertaining control teeth. Boxes limit upper and lower quartiles, while whiskers demark highest and lowest values that are not identified as “outliers”. Outliers (defined as values lying between one and a half and three box lengths from either end of box) are indicated as circles. Horizontal parentheses indicate statistical significances at 5% level ($p<0.05$) within the two groups

Compliance with Ethical Standards

Conflict of Interest:

Senta Fleig declares that she has no conflict of interest.

Prof. Dr. Thomas Attin declares that he has no conflict of interest.

Dr. Holger Jungbluth declares that he has no conflict of interest.

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Ethical approval: All procedures performed in the present study were in accordance with the ethical standards of the institutional and national research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards. Ethical approval was given by the local ethical committee (Kantonale Ethikkommission Zürich, submission No. KEK-ZH-Nr. 2014-0099).

Informed consent: For this type of study, formal consent is not required.

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